A Review of Climate Change Induced Effects on Avian Prey Species and their Consequences for Arctic Fox Populations of Western Iceland

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1.0 ABSTRACT

Island arctic fox populations are considered to carry the future wellbeing of the global population. Iceland has an island population with two arctic fox eco-types: western/coastal and eastern/inland. The western fox population is protected by the Hornstrandir Nature Reserve; no such protection exists for the eastern fox population. Food sources in both regions differ from each other and vary from summer to winter, but reliable and ample winter time food sources are the most critical for fox population's survival. A literature review on arctic foxes and their prey species in the face of climate change is important for understanding possible future scenarios for Iceland's arctic fox populations. Bird species comprise over one-third of the western arctic fox's diet in wintertime. Of these, the rock ptarmigan and guillemots (Brünnich's and Common) alone make up over 50% of the bird species consumed. This narrative review aims first to synthesize studies on how these three avian species will likely react to climate change and second to analyze those reactions' implications for the future wellbeing of the western Icelandic arctic fox. This study finds overall negative effects of climate change on the bird species and implied negative impacts on the western Icelandic arctic fox population, and thus suggests protection of both Icelandic arctic fox eco-types for the sustainability of the Icelandic population as a whole.

INTRODUCTION

2.1 Arctic Foxes (*Vulpes lagopus*) of Iceland: Range, Distribution, and Population

The arctic fox, *Vulpes lagopus*, is a small mammal with a circumpolar distribution that is highly adapted to the Arctic climate (Martínez, 2012; Dalerum, 2012). Arctic foxes' basic social unit is the monogamous breeding pair (Elmhagen, Hersteinsson, Norén, et al., 2014; Martínez, 2012), and there has never been a sustained breeding population outside of the tundra ecosystem (Fuglei & Anker, 2008). It is predominantly found in places where the maximum temperature of the hottest month is not below negative five degrees Celsius or above 25 degrees Celsius, where the average temperature of the hottest quarter of the year is not below negative ten degrees Celsius or above 15 degrees Celsius, or when the average difference between the highest and lowest temperature does not exceed 12 degrees Celsius (Figure 1) (Fuentes-Hurtado, 2016). Currently, Iceland's climate is perfectly suited to the arctic fox, as Iceland's yearly average temperature varies from negative 10 to positive 4 degrees Celsius and the average temperatures in the warmest month is between 0 and 12 degrees Celsius (Figures 2 & 3, *Appendix A*) (Climate in Iceland, n.d.).

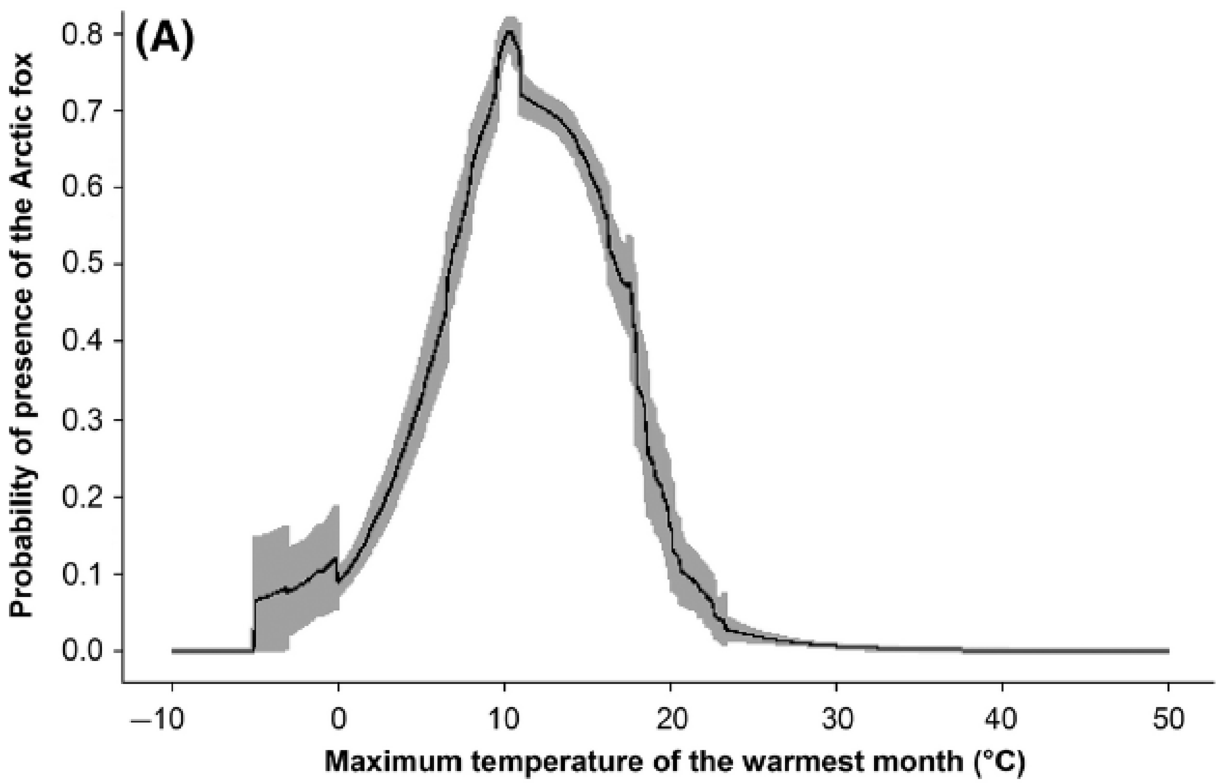

Figure 1: Temperature limits the presence of arctic foxes to Arctic areas (Retrieved from Fuentes-Hurtado, 2016).

The arctic foxes of Iceland are the island's only endemic mammal and distinct from other populations (Fuegli & Anker, 2008). Icelandic arctic foxes are genetically isolated from other populations (Mellows et al., 2012). The Icelandic population was at its maximum size in the 1950s before declining through the 1970s (Pálsson, Hersteinsson, Unnsteinsdóttir et al., 2016). After its 1975 minimum, the population rose through 2003 (Pálsson et al., 2016). From 2008 to 2010, the population decreased to two-thirds of its early 2000's maximum, and the population is still declining (Midgely, 2016). The current estimate places the population at 10,000 foxes distributed throughout Iceland, with the highest distribution in the Hornstrandir Nature Reserve in the Westfjords (Mellows et al, 2012; Midgely, 2016). Because lemmings and other small rodents are not found in Iceland, the Icelandic arctic foxes do not experience the short-term, cyclical population fluxes that lemming-dependent foxes do (Pálsson et al., 2016; Unnsteinsdóttir, Hersteinsson, Pálsson, et al., 2016).

Arctic fox populations are generally divided into insular and continental populations (Pálsson et al., 2016). Although Iceland is a small island, the insular Icelandic population can be broken into two genetically distinct eco-types: western/coastal and eastern/inland (Figure 4) (Norén, Angerbjörn, & Hersteinsson, 2009; Pálsson et al., 2016). The western population is concentrated in the Westfjords region. The Westfjords and the rest of Iceland are connected by a nine kilometer stretch that reduces movement between the two areas and upholds the separation between the two populations (Norén et al., 2009). The eastern population resides in the central highlands region, where the accessibility to coastal resources is much less (Pálsson et al., 2016). While Iceland's coastline is extensive, the amount of productive coastal land in the Westfjords region, although a smaller region in terms of total land area, is double the amount found on the rest of the island (Pálsson et al., 2016). Arctic foxes' access to marine resources is thus greater for the western ecotype than for the eastern ecotype.

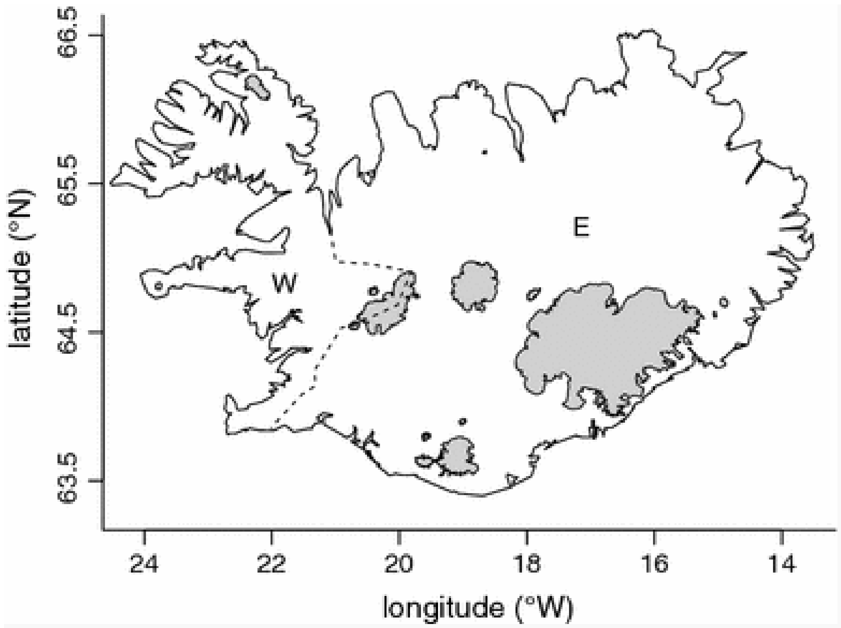

Figure 4: The Icelandic arctic fox population is divided into two eco-types: western/coastal and eastern/inland (Retrieved from Pálsson et al., 2016).

2.2 Arctic Foxes (*Vulpes lagopus*) of Iceland: Diet and Feeding Behavior

Icelandic arctic foxes are territorial and highly competitive (Unnsteinsdóttir et al., 2016). They are solitary hunters (Elmhagen et al., 2014) and opportunistic feeders (Elmhagen et al., 2014; Unnsteinsdóttir et al., 2016; Pálsson et al., 2016). As generalist predators they consume anything from berries and terrestrial mammals to seabirds and fish (Unnsteinsdóttir, 2014; Dalerum et al., 2012).

The particular composition of the arctic fox diet varies depending upon the ecotype. Western Icelandic foxes live predominantly in coastal habitats and thus have diets consisting highly of marine resources (Dalerum et al., 2012; Unnsteinsdóttir, 2014). Iceland's coasts usually remain sea-ice free even in winter, so marine food remains available to arctic foxes in coastal habitats year-round (Dalerum et al., 2012). These marine resources include seal carcasses; seabirds such as common, black, and Brünnich's guillemots, northern fulmar, eider ducks, and their eggs; seaweed; and fish (Dalerum et al., 2012; Unnsteinsdóttir, 2014; & Pálsson et al., 2016). Western Icelandic arctic foxes also eat terrestrially-derived food sources such as sheep carcasses, geese, rock ptarmigan, berries, and passerines (Unnsteinsdóttir, 2014; Pálsson et al., 2016). Eastern Icelandic arctic foxes consume fewer marine food sources and depend more upon passerines, rock ptarmigan, geese, berries, waterfowl, and migratory bird species, owing to fewer productive coastline habitats and the dominance of central highland habitats (Pálsson et al., 2016).

Differences in diet reflect in the two populations (western/coastal and eastern/inland) in multiple ways. Studies have documented differences between insular (typically coastal) populations and continental (typically inland) populations generally as well as Icelandic western and eastern populations specifically. The western population's litter size is more constant among individuals and across years, likely due to the more stable diet (Fuglei & Anker, 2008). The western population's diet high in marine-based food leads it to have on average greater concentrations of ^{13}C and ^{15}N (Dalerum et al., 2012). Coastal arctic foxes have also been recorded with higher levels of mercury (Bocharova et al., 2013). Research on populations of Svalbard inland and coastal arctic foxes found the coastal foxes to have significantly higher levels of persistent organic pollutants in their systems (Andersen, 2015).

Composition of diet also changes seasonally, and it is critical to understand wintertime diet since reliable and ample winter time food sources are the most crucial for an arctic fox population's survival (Stephen James Midgely, personal communication, 30 September 2016). Eastern foxes' diets experience greater shifts in conjunction with the season, feeding more on ptarmigan in the winter and on migratory bird species, including seabirds, in the summer (Norén et al., 2009). Western foxes' diets are less altered by season, due to the greater temporal stability of a marine-based diet (Norén et al., 2009). Bird species comprise over one-third of the western fox's diet in wintertime (Unnsteinsdóttir, 2014). Of these, the rock ptarmigan and guillemot species—Brünnich's and Common—alone make up over 50% of the bird species consumed (Unnsteinsdóttir, 2014). Because of their high contribution to the western arctic fox's diet during wintertime—the time most indicative of species' health—this paper concentrates on the rock ptarmigan, common guillemot, and Brünnich's guillemot. This literature review synthesizes studies on how these avian species will likely react to climate change. It then analyzes those reactions' implications for the future wellbeing of the western Icelandic arctic fox.

2.3 Justification of Study

As the only endemic mammal to Iceland, the arctic fox holds a long history of both cultural and ecosystem value here and contributes substantially to Iceland's biodiversity. Biodiversity is a key indicator of ecosystem health and incredibly important for the long-term sustainability of natural systems (Townsend, Begon, & Harper, 2003). As climate changes, biodiversity is at risk (Townsend et al, 2003). Because organisms depend upon each other, understanding how lower-level trophic organisms will react to climate change can help predict how upper-level trophic levels will react to climate change. And, understanding climate changes' impacts upon organisms will ensure more appropriate, sustainable, and beneficial care and conservation (Reed, Harris, & Wanless, 2015).

Thus, this narrative review aims to synthesize what current research on arctic foxes and their prey species implies for the future of Icelandic arctic foxes in the face of climate change. There is a lack of papers addressing the questions: "How will climate change induced impacts on major prey species of the western Icelandic arctic fox—namely rock ptarmigan and guillemots—influence the western Icelandic arctic fox population?" and consequently "Do these impacts require policy/protection/regulation reconsiderations for Iceland's arctic fox populations?" Most research thus far has studied the effects of climate change on particular species, such as the rock ptarmigan and the common and Brünnich's guillemot. There is extremely limited research applying expected changes in prey species such as the aforementioned avian species to higher trophic levels and dependent predators, such as the arctic fox. Because of the decent extent of research regarding climate change's consequences on rock ptarmigans and guillemots, this literature review focuses on understanding this knowledge and synthesizing its implications for the future wellbeing of the arctic fox. This study finds overall negative effects of climate change on the bird species and implied negative impacts on the western Icelandic arctic fox population, and thus suggests protection of both Icelandic arctic fox eco-types for the sustainability of the Icelandic population as a whole.

3.0 APPLIED METHODOLOGY

To bring together appropriate literature, I needed to first find the available literature on arctic foxes in western Iceland. After determining from the literature that a large portion of the western Icelandic arctic fox's diet are rock ptarmigans and guillemots, I needed to evaluate what the literature says the effects of climate change on these species will be and how changes in these prey species might impact the arctic fox. I then considered if these conclusions suggested a need for improved protection of the Icelandic arctic fox populations.

Literature was compiled by utilizing expert advice, conducting database searchers, and using the snowballing technique (Van Wee and Banister, 2015). Literature was recommended to me by employees of, and researchers at, the Arctic Fox Centre in Súðavík, Iceland. Literature searches were then conducted on four different databases: Falvey Memorial Library, through Villanova University; EBSCO Host, through the School for International Training's Donald B. Watt Library Commons; Google Scholar; and Leitir.is. Search terms included: arctic fox climate change; arctic fox Iceland, arctic fox Iceland climate change, arctic fox diet Iceland, rock ptarmigan climate change, rock ptarmigan Iceland, rock ptarmigan climate change Iceland, guillemot climate change, guillemot Iceland, guillemot climate change Iceland, and arctic birds climate change. As guillemots are also called murres, the same searches as those described above were conducted, but replacing "guillemot" with "murre." Snowballing from the reference lists of papers resulting from database searches was a second technique used (Van Wee & Banister, 2015). By utilizing references from the works cited of papers first found, the depth and breadth of research available expanded greatly. Combining database searches and snowballing therefore strengthened this literature review.

4.0 SPECIES SUMMARIES: ROCK PTARMIGAN, COMMON GUILLEMOT, AND BRÜNNICH'S GUILLEMOT

The rock ptarmigan *Lagopus mutus* lives in Iceland throughout all four seasons (Figure 5) (Bárđarson, 1986). It is highly adapted to a seasonal climate of a snow-filled winter and snow-free summer with its white winter feathers and brown summer feathers (Bárđarson, 1986). During the winter months, it moves to the highlands but stays at or below the vegetation line, since it feeds primarily on vegetation (Bárđarson, 1986). It is important to note that forested areas are not preferable to the ptarmigan (Pernollet, Komer-Niervergelt, Jenni, & Butler, 2015). There are an estimated 60,000 to 230,000 breeding pairs of ptarmigans in Iceland currently (Hilmarsson, 2011).

Figure 5: The rock ptarmigan lives year-round throughout Iceland, except for on the glaciers (Retrieved from Hilmarsson, 2011). *See Appendix for figure key.*

The common guillemot *Uria aalge* is a seabird distributed throughout Iceland's coastal areas, but most copiously in the south (Figure 6) (Bárđarson, 1986). Population estimates place Iceland's common guillemot population at 700,000 pairs after decreasing by 30% since the 1980s (Hilmarsson, 2011). The common guillemot mainly eats sand eel and capelin (Hilmarsson, 2011). It carries one fish per trip; fishes small enough to carry but as large as possible are most efficient in terms of energy and nutritional gains for the common guillemot (Finney, Wanless, & Harris, 1999; Kadin, Olsson, Hentati-Sundberg, Ehrning, & Blenckner, 2015).

Figure 6: The common guillemot lives along Iceland’s coast in winter and breeds in specific areas, as designated by the orange blobs (Retrieved from Hilmarsson, 2011). *See Appendix for figure key.*

The Brünnich’s guillemot *Uria lomvia* is more concentrated in Iceland’s north, but is another seabird that may be found throughout Iceland (Figure 7) (Bárđarson, 1986). There are approximately 330,000 breeding pairs in Iceland (Hilmarsson, 2011). The Icelandic population has decreased by 44% since 1983 (Hilmarsson, 2011). The Brünnich’s guillemot, similar to the common guillemot, also carries only one fish per trip (Gaston, Gilchrist, & Hipfner, 2005), and its main prey is capelin (Hilmarsson, 2011).

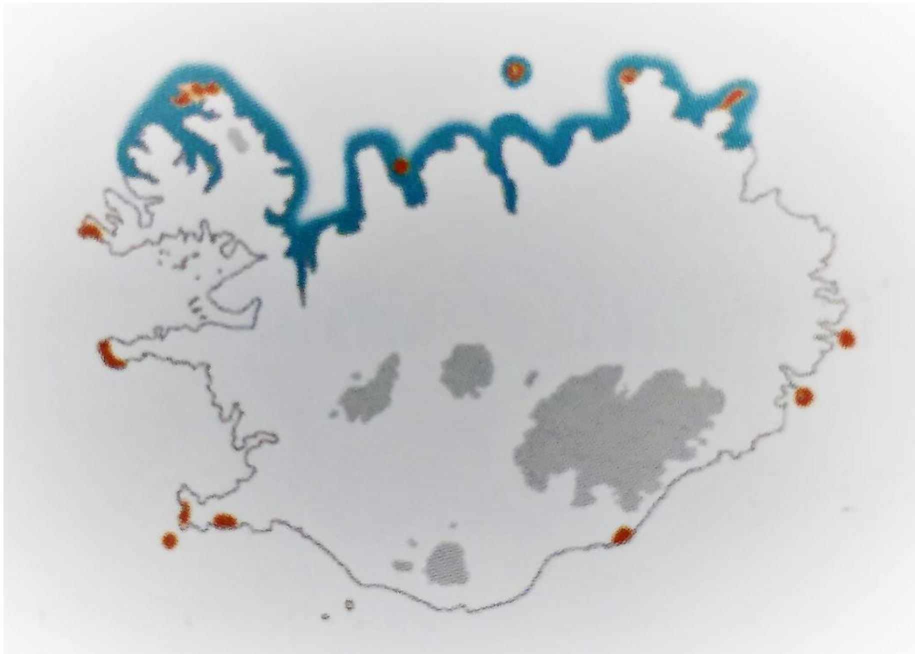

Figure 7: The Brünnich's guillemot breeds in various places throughout Iceland, but winters only in the north (Retrieved from Hilmarsson, 2011). *See Appendix for figure key.*

5.0 CLIMATE CHANGE IN ICELAND

5.1 General Overview

Climate change is occurring more rapidly at higher latitudes (IPCC, 2013). Over the 20th century, the Arctic experienced twice as much warming as the global average, or about 2.1 degrees Celsius (Thorsteinsson, 2016). The area is expected to continue warming to a more extreme extent than other global regions (IPCC, 2013). As a high-latitude island in the North Atlantic Ocean, Iceland's ecosystems are at risk from climate change (Thorsteinsson, 2016). The effects of climate change in Iceland include rising temperature, rising sea level, increasing precipitation, ocean acidification, changing wind patterns, altered primary production in both marine and terrestrial ecosystems, and altered habitat distribution of organisms (IPCC, 2013; *Adapting*, 2012). These factors together will cause wide-ranging impacts on Iceland's biota, such as the arctic fox, rock ptarmigan, and guillemots.

Lauria et al. states that in order to understand how climate affects biota, both direct and indirect effects, especially multi-species interactions, need to be taken into account (2012). Wassmann et al. categorizes the types of documented climate changes effects on Arctic organisms thus far into "range shift, abundance, growth and condition, behavior and phenology, and community and regime shifts" (2013). For avian species in particular, direct effects include deaths from higher wind speeds or extreme temperature events; indirect effects include habitat encroachment by competing species, loss of suitable habitat, and changes in abundance and distribution of prey (Finney et al., 1999). As temperatures increase, species are expected to move northward in order to remain in their preferred climate zones (Frederiksen, Anker-Nilssen, Beaugrand, & Wanless, 2013; Wauchope et al., 2016). On species already far to the north, their range becomes limited because their current distribution cannot move further north (Wauchope et al., 2016). Additionally, climate warming could alter migratory routes, on one or both ends of the migration path (Wauchope et al., 2016). Already Iceland has witnessed decreases in the majority of its seabird populations (*Adapting*, 2012).

What the future climate will look like depends upon a multitude of factors, and how those factors influence individual species directly through physical problems and indirectly through ecosystem alterations cannot be stated exactly. How multi-species interactions play into climate change impacts are often “speculative, [but] [o]n the other hand, predictions that overlook interaction processes would lack realism” (Gilg et al., 2012). This complexity makes synthesizing all of the known information about climate change and individual species (in this case, arctic foxes, rock ptarmigan, and guillemots), as well as taking into account multi-species interactions, necessary for the most informed predictions of the future health of any species.

5.2 Impacts on Rock Ptarmigan (*Lagopus mutus*)

Several studies have investigated the impacts of climate change on rock ptarmigan’s reproductive habits, population size, and distribution. Expectations for the rock ptarmigan’s future are overwhelmingly negative. As a high-altitude species, the rock ptarmigan is considered at particular risk to a warming climate (Novoa, Astruc, Desmet, et al., 2016). With increasing temperatures, the ptarmigan is expected to move higher in altitude or latitude to continue living in its preferred climate and vegetative zones (Novoa et al., 2016), as both altitudinal and latitudinal vegetative movements are expected (Gilg, Sittler, & Hanski, 2009). For example, warming should bring about a higher tree line; as the species avoids forested areas, this would likely negatively impact rock ptarmigans by reducing the extent of preferred habitat (Pernollet, 2015).

Some studies display an alarming story of rock ptarmigan population dynamics. The Swiss population has suffered a decline for over two decades (Pernollet, Komer-Niervergelt, Jenni, & Butler, 2015). In three of four study sites in the Swiss Alps, ptarmigan populations moved upward in elevation over time (Pernollet et al., 2015). When Reverman et al. modeled available, potential future habitats for rock ptarmigans in the Switzerland, they predicted a 66% decrease by 2070, a projection that would prove dire to the Switzerland ptarmigan population and species which prey upon it (2012).

Other studies convey more neutral implications for future rock ptarmigan populations. For example, a six year study on populations of rock ptarmigan found no effects of seasonal weather variability on the survival rates of the birds (Unander et al., 2016). Novoa et al. found no shift of rock ptarmigan populations toward higher altitudes for reproductive habitats (2016). This thirteen year study of rock ptarmigan populations also found no short-term effects on their breeding (Novoa et al., 2016). Despite the median date of hatching for the group displaying no significant change, for nine of the thirteen study years, the date of the first hatching became significantly earlier (Novoa et al., 2016).

From these sources, we can surmise an uncertain future for the rock ptarmigan in Iceland. With Iceland being a small island and thus having limited opportunity for organisms to shift to more desirable habitats, the rock ptarmigan could experience unprecedented decline with climate warming.

5.3 Impacts on Common and Brünnich's Guillemots (*Uria aalge & Uria lomvia*)

There is extensive documentation of the effects of climate change on seabirds. For northern hemisphere seabirds in general, the literature agrees that seabirds at the southern edge of their range limit will be more negatively affected by climate change than members of the same species who inhabit the northern edge of the range limit (Frederiksen, Anker-Nilssen, Beaugrand, & Wanless, 2013; Gaston, Gilchrist, & Hipfner, 2005). Researchers thus suggest a likely northern shift for seabird colonies as the previous southern range extent becomes too warm for inhabitation of both the seabirds and their prey species (Frederiksen et al., 2013; Wauchope et al., 2016). The northward expansion of mosquitos in conjunction with the warming climate is expected to spur northward movement as well, in addition to threatening seabird populations at higher latitudes than in the past (Gaston et al., 2005). For the common and Brünnich's guillemots in particular, literature documents negative, positive, and neutral impacts, as well as direct and indirect effects, of climate change on the species.

In regard to direct, temperature-related threats from climate change, the Brünnich's guillemot may be more at risk than the common guillemot. The Brünnich's guillemot in Norway—a population that winters in Iceland—is expected to become quasi-extinct in 50 years and extinct in 100 years (Descamps, Strøm, & Steen, 2013). Because the Brünnich's guillemot prefers higher latitudes than the common guillemot and thus has less opportunity for northward movement, climate warming's constraining effect on its southern limits will likely be more detrimental to it (Gaston et al., 2005). As Brünnich's guillemot already primarily inhabits the northern areas of Iceland (Hilmarsson, 2011), it is not possible for the Brünnich's guillemot to move northward while remaining in Iceland.

Many studies have found clear, negative associations between climate change, diet, and bird health. Because guillemots are specialized eaters, they are sensitive to food web dynamics (Barrett & Erikstad, 2013). Sandvik et al. found that both the common and Brünnich's guillemots were negatively affected by warmer temperatures causing alterations to their food webs (Sandvik, Erikstad, Barrett, & Yoccoz, 2005). Gaston et al. found that Brünnich's guillemot switched its diet in the mid-1990s from cod to capelin because distribution of the fish species had shifted due to climate change (2005). Because Brünnich's guillemot carries a single fish per foraging trip, eating the smaller capelin instead of the larger cod means that the guillemots must make more frequent trips, thus exerting more energy and spending more time away from the nest (Gaston et al., 2005). Similar results have been documented in the North Sea, with many of the North Sea common guillemot populations decreasing in size in response to their cold water prey species decreasing in population (Evans, Potts, Harris, & Wanless, 2013). Finney et al. also report on a shift to smaller, less energy efficient prey of the common guillemot during negative weather conditions (1999). With predicted increases in the occurrence and severity of stormy weather at higher Northern latitudes during climate warming, these results of struggle during stormy weather do not have positive indications for common guillemot populations, especially given the incidents of thousands of guillemot corpses washed up on beaches after severe storms (Finney et al, 1999; Gilg et al., 2012).

Literature has also found indirect impacts of climate change on guillemot breeding patterns (Frederiksen et al., 2013; Regular et al., 2009). Frederiksen et al. found that the common guillemot tends to bypass breeding in years with high winter sea surface temperature (SST) values (2013). Because El Niño years usually mean high SST values, and climate change will bring more El Niño years, higher rates of breeding bypassing are expected to occur in the future (Frederiksen et al., 2013; Reed et al, 2015). Regular et al. documented that the common guillemot postpones breeding in years after a season when prey species arrive late to the waters of guillemot breeding grounds (2009). Because guillemots are long-lived birds, one or two years of skipped or delayed breeding are not worrying; however, population decline could be a consequence of multiple years of skipped or delayed breeding (Frederiksen et al., 2013; Regular et al., 2009).

Other findings are additionally disconcerting (Reed et al, 2006; Descamps et al., 2013; Irons et al., 2008). Reed et al. found that selection in common guillemots prefers birds who respond similarly to the mean response and disfavors birds who respond differently than the mean response (2006). This implies a lack of selection for birds who are unusually better adapted to changing climate conditions (Reed et al., 2006). Descamps et al. and Irons et al. point to the magnitude of the climate shift over the direction of the shift as explanation for seabird populations succeeding or struggling (2013; 2008). The amount of the change in sea surface temperature explained population dynamics of Brünnich’s guillemot more than the direction of the change in sea surface temperature (i.e. warming or cooling) (Descamps et al., 2013). In fact, large fluctuations in sea surface temperature in either direction negatively impacted both the common and Brünnich’s guillemots (Irons et al., 2008). Those results lead Irons et al. to predict an overall negative reaction of the Brünnich’s guillemot to climate warming (2008).

Other literature implies neutral or positive climate change effects on the Brünnich’s and common guillemots (Krasnov, Barret, & Nikolaeva, 2007; Frederiksen, Harris, Daunt, Rothery, & Wanless, 2004). Slight ocean warming seems to have positive effects on several common guillemot populations (Regular et al., 2010; Barret & Erikstad, 2013; Irons et al, 2008). Higher winter abundance of one population of the Brünnich’s guillemot displays how mildly warmer sea surface temperatures are benefitting it as well (Veit & Manne, 2015). Krasnov et al. found that five of the five colonies of the Brünnich's guillemot and four of the five colonies of the common guillemot they studied had stable populations (2007). Furthermore, the one declining population of the common guillemot is linked to an abnormally cold year in that region, which likely explains the crash in the common guillemot's prey species and thus the crash in the guillemot population itself (Mesquita et al., 2015). Since climate change is increasing temperatures in the Arctic, this result does not suggest a negative future for the bird in a warming climate (Mesquita et al., 2015). Expected increases in Arctic primary productivity (Frey, Arrigo, & Gradinger, 2011) suggest positive reactions in guillemot populations too (Wong, Gjerdum, Morgan, & Mallory, 2011). In Arctic waters with higher primary productivity, both the common and Brünnich's guillemots displayed higher abundance and densities (Wong, Gjerdrum, Morgan, & Mallory, 2011).

The literature displays a mixture of expectations for the fate of the guillemots in the face of climate change. As such, predicting specific results by species may not be entirely realistic at this time (Wong et al., 2011; Carey, 2009). Studies convey positive, negative, and neutral effects of changes in climate on guillemot populations. However, even the studies that find more positive impacts explicitly communicate the need for continuous investigation and population monitoring in order to ensure the highest level of safety and success possible for the bird populations (Wong et al., 2011; Kadin, Österblom, Hentati-Sundberg, & Olsson, 2012; Veit & Manne, 2015). Additionally, this review found a greater extent of negative than positive predictions and a larger amount of negative effects. Overall, concern for the future of guillemot populations is thus warranted, specifically in relation to their importance for the western Icelandic arctic fox.

6.0 DISCUSSION

6.1 Implications for Future of Arctic Foxes (*Vulpes lagopus*) in Iceland

The arctic fox has been documented to react to climate change throughout its Arctic habitats, both in cyclic, continental populations and in insular populations such as Iceland's (Killengreen et al., 2007; Fuglei & Anker, 2008; Hof et al., 2012; Pálsson et al., 2016). Although insular arctic fox populations have been considered the future security deposit of the species (Fuglei & Anker, 2008), the literature synthesized in this review points to a more uncertain future of the arctic fox in Iceland due to changes in prey dynamics.

Since the western Icelandic arctic fox depends upon both marine and terrestrial based prey, alterations in either (or both) ecosystems would presumably impact the arctic fox (Pálsson et al., 2016). Indirectly, climate change could impact lower trophic levels and effect the arctic fox through bottom-up control (Townsend et al., 2003). Variations in distribution and/or abundance of organisms throughout trophic levels are likely as temperatures and precipitation increase in Iceland (*Adapting*, 2012). As seabirds making up about 30% of the consumed avian species (Unnsteinsdóttir, 2014), the guillemot species are essential contributors to the stability of the western Icelandic arctic fox's marine-based diet. Questions about the futures of the common and

Brünnich's guillemots remain, as obvious from the variability in the results of climate change studies thus far. However, the researches' emphasis on uncertainty and the greater extent of negative predictions, especially for the Brünnich's guillemot, generate viable concern for the arctic fox. Decreases in abundance and shifting distribution of these avian species, especially during winter, would likely result in a struggling arctic fox population.

The Icelandic arctic fox population as a whole has historically displayed negative reactions to dips in ptarmigan populations (Pálsson et al., 2016). With the expectation that the rock ptarmigan will move toward higher elevations (Novoa et al., 2016), coastal Iceland might experience a severe dip in ptarmigan numbers as the bird shifts to the central highlands. While the exact reaction of the arctic fox population cannot be predicted with certainty, typically decreases in prey population sizes lead to responsive declines in predator species (Townsend et al., 2003). It is also possible that the arctic fox enacts top-down pressure upon the rock ptarmigan by increasing reliance on it if guillemot populations crash or change their migratory patterns. Since any shift in predator-prey relationships can lead to an unsustainable dynamic, a top-down effect could also lead to negative consequences for the arctic fox (Townsend et al., 2003)

As this review communicates, the futures of the common and Brünnich's guillemots and rock ptarmigan in Iceland are uncertain yet riddled with substantial negative predictions, and climate change has already led to changes in distribution, abundance, breeding behavior, and feeding habits of all three of these avian species (Frederiksen et al., 2013; Gaston et al., 2005; Sandvik et al., 2005; Anderson et al., 2013; Finney et al., 1999; Gilg et al., 2012; Descamps et al., 2013; Novoa et al., 2016; Pernollet et al., 2015). Such indirect effects of climate change through declines in important prey populations could prove a consequential threat to the sustainability of the arctic fox in Iceland, especially as coastal eco-type arctic foxes have been previously documented to react to shifts in availability of its prey species (Eide, Eid, Prestrud, & Swenson, 2005; Eide, Stien, Prestrud, Yoccoz, & Fuglei, 2012; Pálsson et al., 2016). Given that there has never been a sustained breeding population of arctic foxes outside of the tundra ecosystem, an altered tundra ecosystem and reduced tundra extent, two realistic facets of the future climate, could prove devastating to the arctic fox in Iceland (Fuglei & Anker, 2008). Its specific temperature requirements (Fuentes-Hurtado, 2016) and homogeneity and uniqueness in genetic make-up (Mellows et al., 2012) highlight this direct risk, as genetic similarity within a population weakens that population's ability to adapt to new conditions (Townsend et al., 2003). However, as an opportunistic feeder, there is also the possibility that the arctic fox switches to new prey species, such as geese, without harm to the population (Pálsson et al., 2016).

6.2 Implications for Management Practices

With an unpredictable future for the arctic fox, sustainable management and proactive care are necessary (Hof, Jansson, & Nilsson, 2012). This becomes especially important if the fate of the arctic foxes' future lies with the insular Icelandic population. Currently, the western Icelandic arctic fox has protection through the Hornstrandir Nature Reserve (Madrigal & Kühn, 2014). Contrastingly, no land is set aside for the eastern population. Since the two eco-types are genetically distinct and depend upon different prey species (Mellows et. al, 2012; Unnsteinsdóttir, 2014), the most far-sighted course of action would include protection of both the western and eastern eco-types. Management of both populations would work toward the sustainability of the eco-types individually in addition to the Icelandic arctic fox species as a whole. If climate change disrupts marine-based prey, the future of the western Icelandic arctic fox could become endangered. With no protected space set aside for the eastern population, the wellbeing of the arctic fox in Iceland would be put greatly at risk. Moreover, if climate changes drastically, Iceland could become an unfit location for arctic fox populations, possibly making protected land a fruitless endeavor. For the time being, however, protection for both eco-types increases the likelihood of a successful future for the arctic fox in Iceland as a whole, and based on the concerning results of this review, greater protection of Iceland's arctic fox population would be prudent.

7.0 CONCLUSION

7.1 Limitations of Current Study and Future Research

As a literature review, this study was limited by variation in the extent and geographic focus of research among the arctic fox, rock ptarmigan, and guillemots in regard to climate change in Iceland. Furthermore, complications arise when it comes to ecosystem functioning in the face of climate change because speculations outnumber "documented impacts" in regard to the effects of climate change, especially on Arctic marine biota (Wassmann, Duarte, Agustí, & Sejr, 2010), and it is difficult to predict population dynamics (Gilg et al., 2009). The quantity of available research about the western Icelandic arctic fox was greater than that of either the rock ptarmigan or the guillemots in western Iceland specifically. However, the amount of research regarding how bird species react to climate change not specifically limited to Iceland far exceeded how coastal eco-type arctic foxes might react to climate change. Thus, since this review primarily synthesized studies of the species individually, understanding of the impact of climate change on coastal eco-type arctic fox diet in Iceland could be improved by further research into multi trophic level interactions in Iceland. Increased modelling of anticipated future species' distributions, such as that done by Pernollet et al., would bolster understanding of future guillemot and rock ptarmigan populations in Iceland and thus possible consequences for the arctic fox.

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<u>9.0 APPENDIX</u>

9.1 Appendix A: Additional Figures

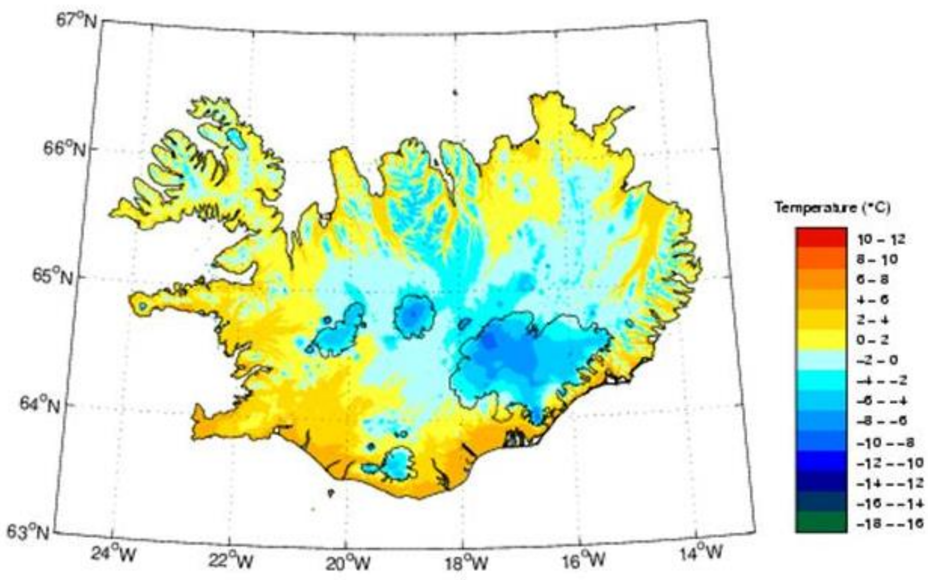


Figure 2: The average yearly temperatures in Iceland (Retrieved from Climate in Iceland).

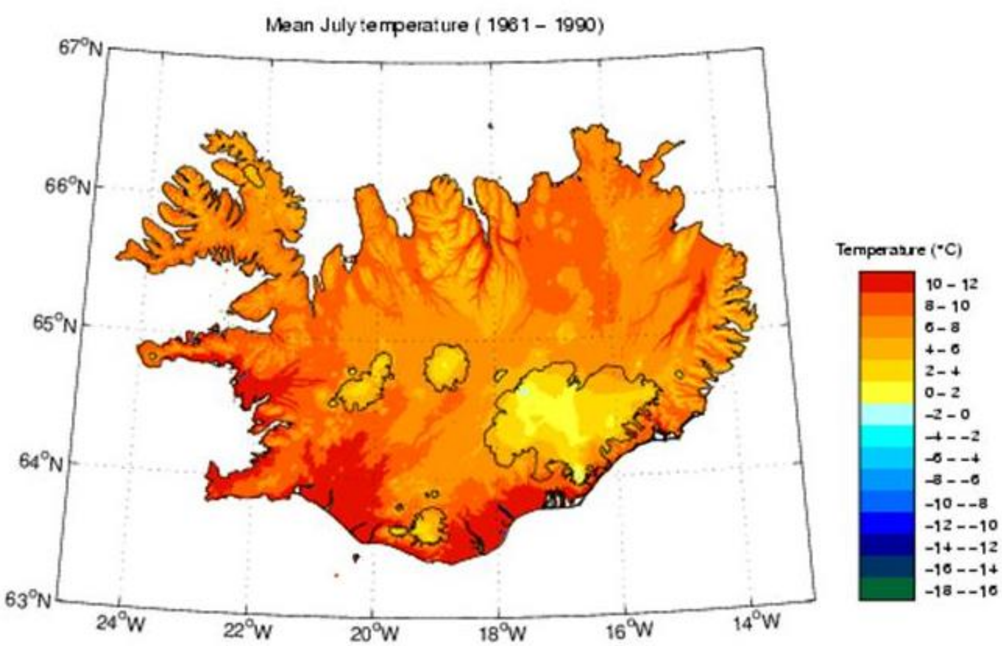
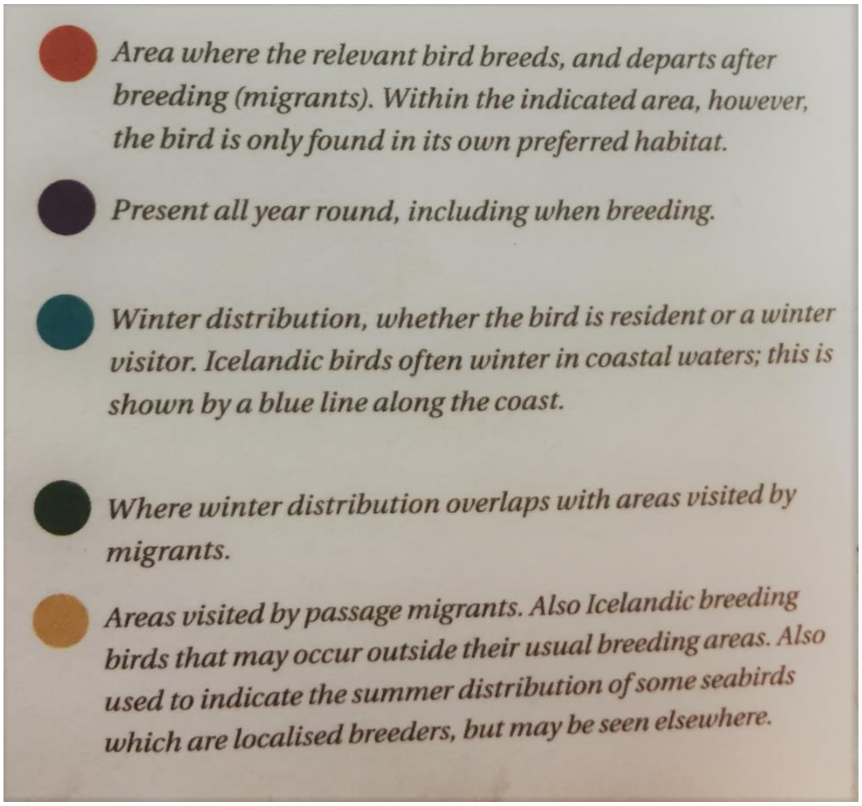


Figure 3: The average July temperatures throughout Iceland (Retrieved from Climate in Iceland).



Area where the relevant bird breeds, and departs after breeding (migrants). Within the indicated area, however, the bird is only found in its own preferred habitat.

Present all year round, including when breeding.

Winter distribution, whether the bird is resident or a winter visitor. Icelandic birds often winter in coastal waters; this is shown by a blue line along the coast.

Where winter distribution overlaps with areas visited by migrants.

Areas visited by passage migrants. Also Icelandic breeding birds that may occur outside their usual breeding areas. Also used to indicate the summer distribution of some seabirds which are localised breeders, but may be seen elsewhere.

Figure 8: The key for the bird distribution maps. (Retrieved from Hilmarsson, 2011).

9.2 Appendix B: Supplemental Fact Sheet

ARCTIC FOXES OF ICELAND:

What Impacts of Climate Change on their Prey Species Mean for the western Icelandic Arctic Fox

√ Temperatures are increasing 2x faster in the Arctic than in the rest of the globe

√ Climate change is causing overall negative reactions in bird species

√ Birds comprise over one-third of the western Icelandic arctic fox's diet in wintertime

√ The rock ptarmigan, common guillemot, and Brünnich's guillemot are three of the most consumed bird species

DID YOU KNOW?

Reliable and ample winter time food sources are the most critical for arctic fox survival.

COMMON GUILLEMOT

- Scientific names *Uria aalge*
- A mid-high latitude seabird
- Expected that warming ocean temperatures will alter the distribution & abundance of its prey species
- Might experience population declines from altered food webs

THE ROCK PTARMIGAN

- Scientific name *Lagopus mutus*
- A high latitude & altitude bird
- Overwhelmingly negative predictions in the face of climate change
- Expected to experience range restrictions from temperature increases and vegetation movement

BRÜNNICH'S GUILLEMOT

- Scientific name *Uria lomvia*
- A high latitude seabird
- Expected to struggle because of severe range restrictions from warming temperatures, increased competitor presence, and limitations of an altered food web

IMPLICATIONS:

Since the western Icelandic arctic fox relies on these species, it could experience population declines. As an opportunistic hunter, however, the arctic fox might adapt to new food choices.